Kyösti Laukkanen, Rainer Laaksonen

Base course stabilization development project INFRA-STABIL

Summary report

Finnra reports 48/2007

TIEHALLINTO
FINNISH ROAD ADMINISTRATION

Kyösti Laukkanen, Rainer Laaksonen

Base course stabilization development project INFRA-STABIL

Summary report

Finnra reports 48/2007

Finnra
Helsinki 2007

Cover picture: Matti Juola, Andament Oy

ISSN 1457-9871
ISBN 978-951-803-968-9
TIEH 3201073E

Internet pdf (www.tiehallinto.fi/julkaisut)
ISSN 1459-1553
ISBN 978-951-803-969-6
TIEH 3201073E-v

Edita Prima Oy
Helsinki 2008

This publication is available at:
asiakaspalvelu.prima@edita.fi
Fax +358 20 450 2470
Telephone +358 20 450 011

Finnish National Road Administration (Finnra)
Opastinsilta 12 A
P.O.Box 33
00521 HELSINKI
FINLAND
Telephone +358 204 22 11

Kyösti Laukkanen, Rainer Laaksonen: Base course stabilization development project INFRA-STABIL. Summary report. Helsinki 2007. Finnish National Road Administration, FINNRA Report 48/2007. 23 p. ISSN 1457-9871, ISBN 978-951-803-968-9, TIEH 3201073E.

Key words: base course, trial, composite, blast furnace slag, remix, cement, stabilization, foam bitumen, service life, product approval

ABSTRACT

The project "Service life and product approval of base course stabilizations – Infra-Stabil" was carried out during 2004-2007. This Summary report includes its essential results.

The study consisted of three parts:

- Development of bituminous base course stabilization
- Full scale trials with stabilized road bases
- Development of base course stabilization service life evaluation and product approval.

The results of the project are shown in six different reports, which have been published on the internet site of the Finnish Road Administration: www. tiehallinto.fi. The Summary report has been published both as a paper publication and on the internet in English and in Finnish.

In Finland base course stabilization is usually made using existing raw material from the construction site and this will set definite limitations for following exact recipes of mix composition. However, a successful stabilization result requires that the stabilization method is chosen based on the properties and conditions of the road, also assuming enough time has been allowed for preliminary planning, the mix composition stays in the defined area and that the stabilization course is compacted properly.

The essential results of the project were:

- changing the mix compositions (gradation and binder content),
- identifying that anti-stripping agent must usually be used in a foam stabilization mixture,
- changing methods in specimen preparation and mix design,
- changing test methods,
- confirming the dominating effect of compacting to quality both in the laboratory and on site,
- identifying that the number of freeze-thaw cycles has a significant effect on the stiffness modulus and consistency of deformation resistance,
- producing research material for the basis of the requirements readjustment for stabilizations,
- obtaining reference data for possible product approval studies of stabilizations,
- developing service life evaluation methods for stabilizations.

The essential results of the project were taken into account in the construction specifications at the same time as the research project was completed.

FOREWORD

The study is a part of the INFRA technology programme project "Service life and product approval of road course stabilizations" (Infra-Stabil). The research was financed by Tekes – The Finnish Funding Agency for Technology and Innovation, FINNRA, Destia, Andament Oy, Lemminkäinen Corporation, NCC Roads Oy, Skanska Asfaltti Oy, Valtatie Oy, Rautaruukki Corporation and Finnsementti Oy. The project management group consisted of:

Lars Forstén	Lemminkäinen Oyj, Chair
Tom Warras until 31 August 2005	TEKES
Osmo Rasimus 1 September 2005 – 31 May 2006	TEKES
Ilkka Jussila since 1 September 2006	TEKES
Harto Räty until 28 February 2006	Infra technology programme
Kari Lehtonen	FINNRA
Teuvo Kasari	Destia
Seppo Määttänen	Lemminkäinen Oyj
Harri Ahola	Skanska Asfaltti Oy
Jukka Juola	Andament Oy
Alpo Mänttäri until 31 December 2005	NCC Roads Oy
Petri Järvensivu since 1 January 2006	NCC Roads Oy
Sami Horttanainen	Valtatie Oy
Marko Mäkikyrö	Rautaruukki Oyj
Pia Rämö	Finnsementti Oy

In addition, the extended management group steering the research consisted of:

Arvo Lähde	FINNRA, Vaasa Road District
Mats Reihe until 31 December 2006	FINNRA
Tuomo Kallionpää	FINNRA
Katri Eskola	FINNRA
Taina Rantanen until 30 April 2005	Ins.tsto A-Tie Oy
Laura Apilo until 31 August 2005	VTT
Heikki Kukko since 1 September 2005	VTT
Rainer Laaksonen	VTT
Kyösti Laukkanen	VTT

The project management established a sub-committee to steer the research methods and technical research issues, including

Lars Forstén	Lemminkäinen Oyj
Ilmo Hyyppä	until 30 April 2006 Helsinki University of Technology
Ville Alatyppö since 1 May 2006	Helsinki University of Technology
Rainer Laaksonen	VTT
Kyösti Laukkanen	VTT

The research report was compiled by Kyösti Laukkanen, M.Sc.(Eng.), and Rainer Laaksonen, M.Sc.(Eng.), VTT.

Helsinki, December 2007

FINNRA

Contents

1 GENERAL

The "Service life and product approval of base course stabilizations – Infra-Stabil" project, a part of the INFRA technology programme, was conducted between 2004 and 2007. This summary report includes its key results.

Course stabilization is a method of improving the road structure in which the sub-base or the base course, or the upper part of the base course, is bound using bitumen, cement or blast furnace slag or a combination of these. Stabilization is carried out both when constructing new roads and renovating old roads. Typically, base course stabilization is used for improving the structure of an old road, and the method utilises existing material from the old road. Alternatives to stabilizations are an unbound base course of crushed aggregate or a asphalt concrete base course. The stabilization improves the bearing capacity of the road.

The goals of the research were to:

- improve the methods of assessing the service life of stabilization and to produce the required laboratory test parameters,
- improve stabilization know-how and research knowledge,
- produce a method for assessing the service life and product approval of new stabilization methods and products,
- explore possibilities of standardising the product approval procedure of base course stabilization with Sweden or possibly Norway.

The research comprised of three sub-studies:

- research on developing bitumen-containing base course stabilizations
- full-scale tests,
- developing the service life assessment and product approval of stabilizations.

The research to develop bituminous base course stabilizations aimed at creating a base for the development of experimental methods for assessing the service life of stabilizations and to improve stabilization know-how and research knowledge.

The full-scale test studied base course stabilization types conforming to existing FINNRA construction documents and created reference data for stabilization service life analysis and product approval.

The third sub-study explored base course stabilization types conforming to FINNRA specifications with laboratory experiments, with the aim of developing an experimental method for assessing service life and gathering reference data for product approval research.

The project was concentrated on the study of the five different stabilization types mentioned in the table 1.

Table 1. Definitions of the studied stabilization types.

Stabilization		Definition
abbreviation	type	
VBST	Foam bitumen stabilization	Bitumen stabilization in which the added binder is bitumen foamed with water
REST	Remix-stabilization	Bitumen stabilization by the Remix method
KOST	Composite stabilization	Stabilization in which are both bituminous and hydraulic added binder in same course
MHST	Blast furnace slag stabilization	Stabilization in which the added binder is blast furnace slag with cement activator
SST	Cement stabilization	Stabilization in which the added binder is cement.

2 RESEARCH RESULTS

2.1 Development of bitumen-containing course stabilizations

The sub-research to develop bitumen-containing course stabilizations included laboratory tests for foam bitumen stabilization, Remix-stabilization and composite stabilization mixtures. The following tasks were carried out for the selected stabilization types (foam bitumen stabilization, Remixer-stabilization and composite stabilization):

- the properties of the stabilization types and factors affecting them were explored using literature studies, previous studies and laboratory tests, mainly utilising the current methods,
- the sample preparation, mix design and research methods suitable for stabilization mixtures were explored and developed as necessary,
- a foundation was laid for the development of methods for assessing the service life of stabilizations.

Defined guideline grading curves A - C for the studied stabilization mixtures are shown in the figure 1.

Based on the laboratory tests it was found that, technically, the best bitumen stabilization results are achieved by:

- using proportioned crushed rock material from the mid-range of the gradation curve specified in the Finnish Asphalt standards 2000,
- choosing the bitumen content so that the mixture is coherent but not susceptible to deformation,
- ensuring the sufficient water resistance of the mixture,
- compacting the stabilized course well.

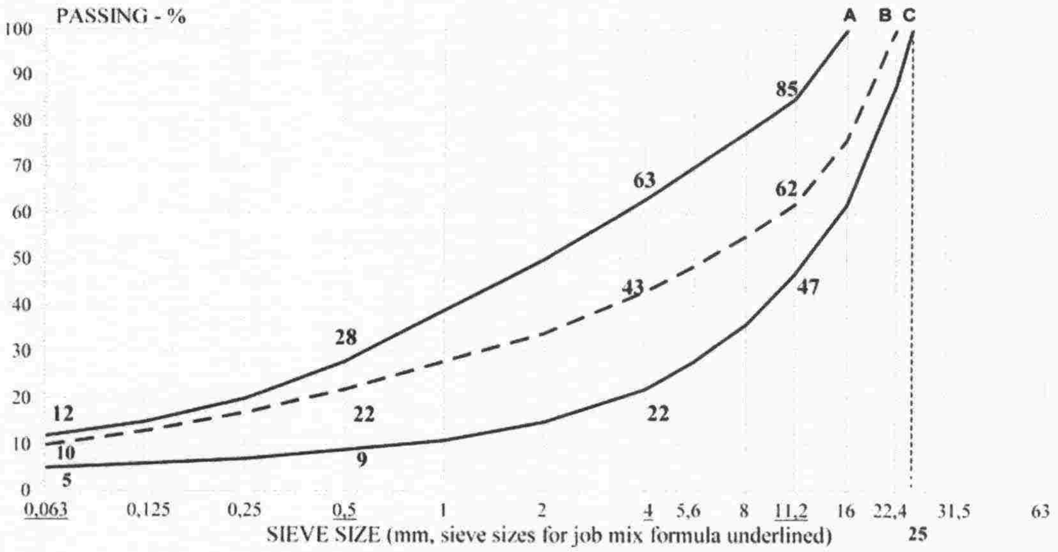

Figure 1. Guideline grading curves A - C for the studied stabilization mixtures

The key factors influencing the properties of stabilizations are binder content, gradation, density and coherence of the mixture. Water content and moisture conditions have an effect on the properties of the stabilization in sample preparation, during the storage of samples, time of testing as well as in the road structure. The results of the research present the data on the effect of these parameters on the functional properties of the mixture, comprising of various studies. Particular attention should be paid to correct compaction both in laboratory and on-site conditions.

Developing a method for assessing the service life of stabilizations based on laboratory and field tests was an important part of the research, including the development of reference materials designed for service life assessment (e.g. development of a reference filler comprising of minerals), development of reference stabilization mixture research methods and exploring the functional properties of the studied stabilization types and the sensitivity of their composition parameters using current methods.

Foam bitumen stabilization (VBST)

Based on proportioning tests, foam bitumen stabilization conforming to the selected desired composition containing an anti-stripping agent had a good water resistance. Reduction in binder content or density below the target value impaired the water resistance. If no anti-stripping agent was used, the VBST mixture was not water resistant.

The deformation resistance of the mixture with the desired composition was good. The mixture did not withstand in the deformation test when bitumen content increased by more than 1% over the target level selected in the proportioning or when softer bitumen (650/900) was used. Results of the VBST mixture stiffness modulus test were very sensitive to temperature changes.

Remix-stabilization (REST)

A Remix-stabilization is a bitumen stabilization made by the remix method. Water resistances of the studied compositions of the REST mixture were good. Reduced density impaired in particular the water resistance of the mixture containing the most fines. Frost resistance and salt-frost resistance were tested using the target composition selected in the proportioning and were found to be sufficient. Temperature and density had a significant effect on the level of the stiffness modulus of the REST mixture.

The deformation resistance of REST mixture was good using the bitumen contents used in practical on-site conditions. Bitumen content conforming to empirical stabilization formula was approximately one percentage unit higher and resulted in deformation-sensitive mixtures.

Composite stabilization (KOST)

A composite stabilization contains both bitumen and cement as binder in the same layer. A cement / bitumen ratio of 0,33 is a good basis for the mix design of a composite stabilization. Change in the cement content readily influences the stiffness of composite stabilization. The study indicated that a cement content of approximately 1 % was well-suited for composite stabilization, figure 2.

The cement binds extra water in the mixture and accelerates the increase of the initial strength of the mixture. Composite stabilization had an exceptionally good deformation resistance and low sensitivity to temperature. Composite stabilization met the water resistance, frost resistance and salt-frost resistance requirements.

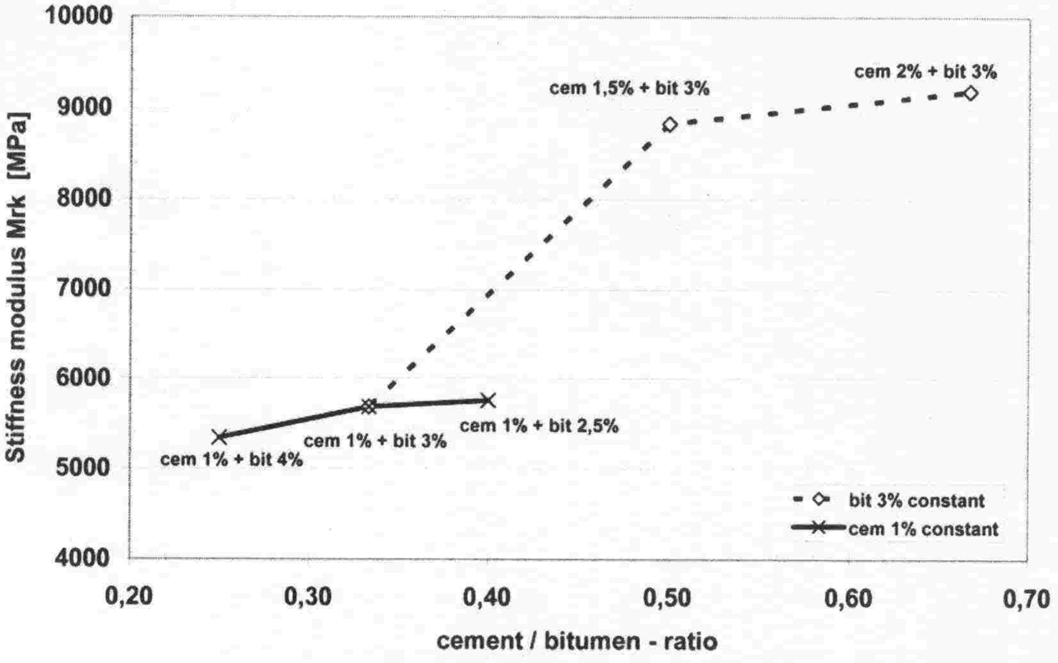

Figure 2. Composite stabilization dynamic stiffness modulus dependence on cement / bitumen ration and binder contents, T = 15°C

2.2 Full-scale tests

The full-scale test of the stabilization methods was carried out during the project in the Vaasa Road District, with a structure improvement project between Kaitsor and Vöyri (road number 718), [3]. The following stabilization types (followed by abbreviation and stabilization depth in mm) were tested in the test road in test sections of 200 to 300 metres:

- foam bitumen stabilization (VBST 100 and 150 mm and 100 mm course with 1% higher bitumen content)
- remix stabilization*) (REST, 100 and 150 mm)
- composite stabilization (KOST 100 and 150 mm and 100 mm course with 1% higher bitumen content)
- blast furnace slag stabilization (MHST 100 and 150 mm).

*) The site was supplemented with additional recycled asphalt (thickness 40 to 50 mm) after premixing with milling.

A premixing with milling section (without the addition of binders) and a FINNRA specification-compliant REST section were made as reference sections for these, Figure 3.

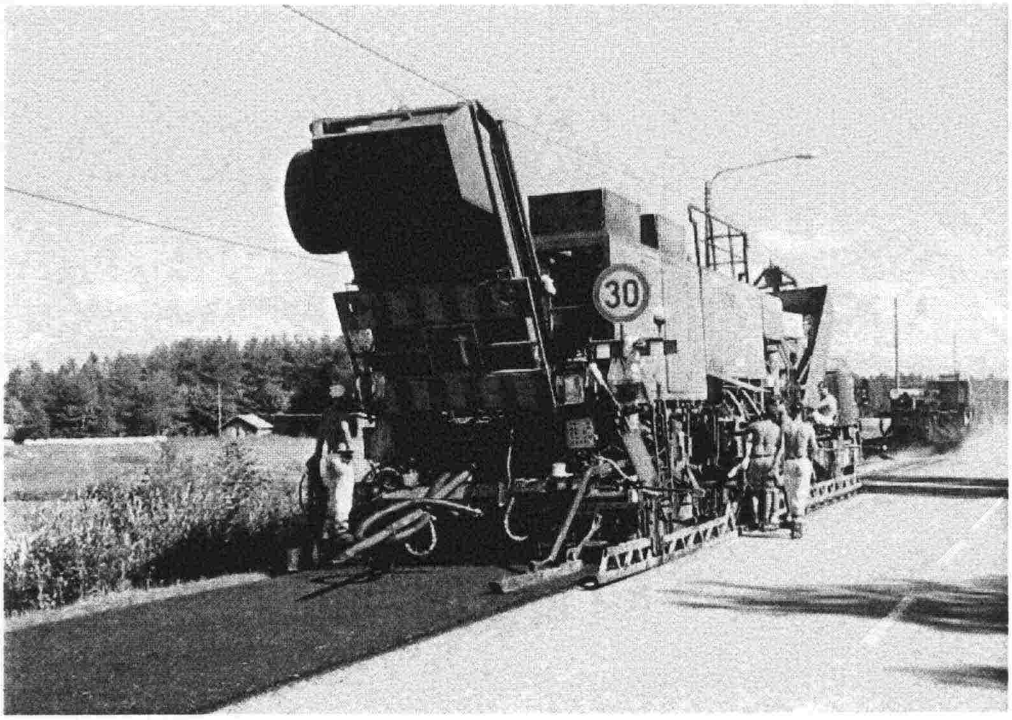

Figure 3. Remix-stabilization.

As a general rule, the execution of the full-scale test succeeded well. The study resulted in stiffness and durability data for the materials, based on samples made at the actual site. The results are usable as reference stabilization type design parameters in service life design calculations. Continued monitoring (even after the completion of this research project) will yield additional information on the changes of the studied stiffness and durability properties over time. This information will be subsequently supplemented by the effects of other properties influencing performance.

As it was not possible to test cement stabilization on the Vöyri test road, full-scale test results for it were obtained from previous test construction projects. At two cement stabilization sites (main road 5 between Vehmasmäki – Hiltulanlahti and main road 6 at Vuoksenniska bypass), the measured bearing capacities varied significantly, clearly illustrating the state of the cement stabilized course under the bitumen surface layers. It would be desirable to monitor the state of these test sections by way of surface measurements and sampling for years (at least 10 years) in order to obtain explicit data on the damage mechanisms connected with the stabilization type.

Based on the laboratory tests of in-situ specimens, one may state that the most important variable in the preparation of samples for preliminary and follow-up tests is density, followed by the moisture conditions at the time of testing. The testing age of the samples has less effect, but stiffness and durability increasing over time should be kept in mind when utilising the test results. Design cannot count on after-compaction, because in practice after-compaction causes considerable rutting in the surface.

The stiffness modulus results from the laboratory tests are somewhat higher than back-calculated values if using comparable sample density, and considerably higher (over-optimistic) using (over)compacted samples conforming to the normal methods in the field (gyratory compactor CEN settings and 100 working cycles). Correct, representative parameters must be used when designing the structure - if over-optimistic stiffness values are used, the design produces clearly unrealistic loading numbers.

Increasing the bitumen content over normal (+1 percentage unit) did not have a beneficial effect on the measured variables stiffness, strength or bearing capacity in the in-situ specimens (VBST, KOST). Stiffness and strength decreased following the addition of bitumen. The extra bitumen did not, however, increase the rutting speed at Vöyri during the follow-up period. The effect of additional bitumen may become evident only in performance monitoring over a longer term, e.g. as a decrease in damage speed.

A two-year follow-up period is insufficient when comparing structures whose presumed / desired service life is 15 years. No abnormalities or damages measured from the surface appear in two years unless there is an obvious design, work or material defect. Monitoring conducted during the first years, however, describes initial quicker changes, e.g. those caused by compaction.

2.3 Assessing the service life of stabilizations and developing product approval

The sub-study aimed at acquiring basic data for the development of assessment methods of the service life of base course stabilizations and to produce research-based service life data, as well as producing reference data for four base course stabilization types for the product approval of new stabilization products. These reference materials were: foam bitumen stabilization (VBST), composite stabilization (KOST), blast furnace slag stabilization (MHST) and cement stabilization (SST).

The study presents two methods of defining the service life of stabilized material. The first method defines the service life experimentally with the help of a similar reference product. The second method is based on experimental determination of the durability of a design parameter (e.g. stiffness modulus) and calculation of service life using technical design methods.

In the study, test series were conducted for the four reference stabilization types, determining their salt-frost resistance and the dependence of stiffness and deformation properties (or alternatively strength properties) on the number of frost cycles. The material also includes the examination of the sensitivity of these parameters to changes in gradation, bitumen content and density.

The results indicate that the number of freeze-thaw cycles has a significant effect on the consistency of the stiffness and deformation resistance of stabilized courses. Laboratory-determined design parameters (stiffness modulus and deformation resistance) should thus be determined also after freeze-thaw cycles. Usually, the change took place mainly during the first 20 freeze-thaw cycles, Figure 4.

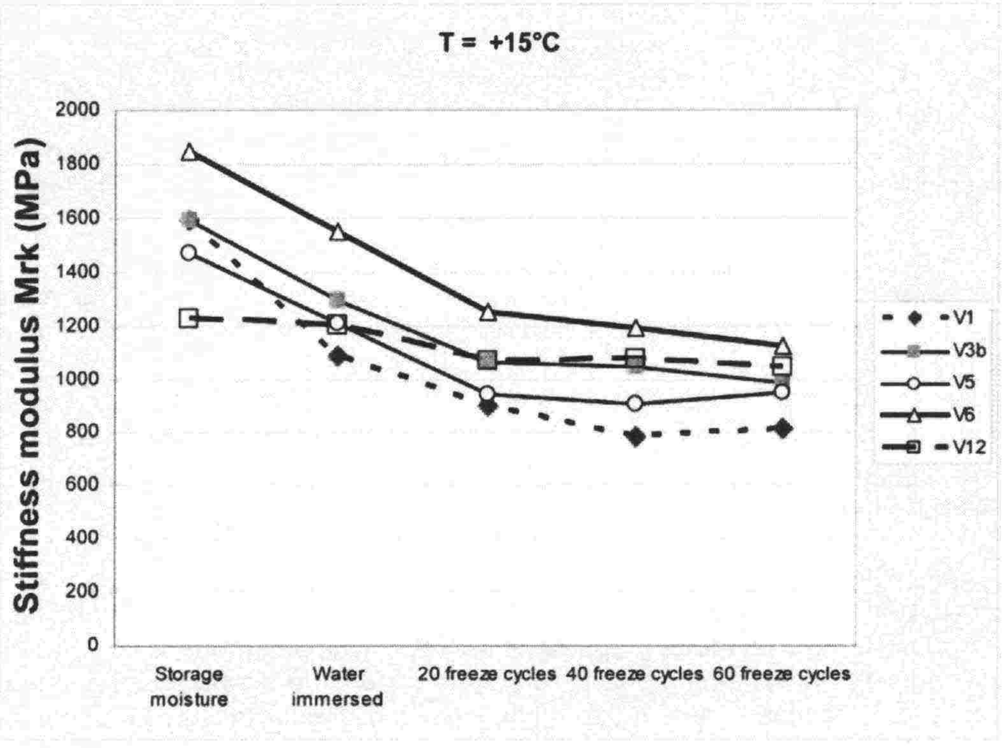

Figure 4. *Dependence of VBST composition stiffness modulus on moisture and the number of frost cycles (uniaxial dynamic stiffness modulus test).*

2.4 Utilisation of the research results

The migration of the research results into construction practice already began while the INFRA-STABIL project was in progress. The stabilization specification was verified by a team consisting of representatives of stabilization contractors, binder suppliers, FINNRA and VTT. Stabilization-related issues in the Finnish Asphalt specifications were included in the Stabilization specification.

3 ASSESSMENT OF METHODS

3.1 Proportioning methods

The proportioning methods for stabilization mixtures were considered to require revisions, especially with regard to warm-mixed Remixer stabilization mixtures containing recycled asphalt. For these, the empirical formulae in the Stabilization specification 2002 suggested a too high bitumen content causing a deformation risk.

3.2 Laboratory test methods

The EN-product standard-compliant deformation test EN 13108:20 for base course asphalt concrete specifies a testing temperature of 40 °C and it is not necessary change in deformation tests of stabilizations.

The proportioning methods of the Stabilization specification in use at the time of the research have been harmonized and their number has been decreased. However, it is necessary to preserve the possibility of using both empirical and experimental proportioning methods in the preliminary testing of stabilization mixtures.

When preliminary tests are carried out for stabilization work, the target mixture density, optimum water content with regard to compaction, water resistance and binder content should be explored. Gradation distribution should be within the specified limits. In this study the coarsest gradation alternative C produced difficult to compact, fragile mixtures (Figure 1). This gradation corresponded to the lower limit of the specified limits for stabilization mixtures in the Finnish Asphalt standards 2000, and the need for revision was established.

Foaming of bitumen in laboratory conditions was found to be successful both with a foaming device and in an open foaming vessel. Preliminary tests identified a suitable bitumen temperature of 170°C and a foam water content of 2.5% as suitable foaming parameters.

An anti-stripping agent should be used in the VBST mixture, unless it can be experimentally proven that no anti-stripping agent is necessary. The need for an anti-stripping agent can be determined by means of a water resistance test based on indirect tensile strength. An anti-stripping agent may be necessary regardless of whether the mixture contains recycled asphalt or whether it is prepared cold or heated. A separately-added anti-stripping agent was not necessary in KOST and REST stabilization with the tested compositions, as the cement in KOST reduces the need for a bonding agent and the emulgator of REST also has a bonding-improving effect.

VBST samples should be stored in dry conditions and KOST samples in humid air until the testing can be initiated.

The current status of stabilization testing methods in the Nordic countries was explored by means of a literature study. It was found that the testing and proportioning methods for stabilizations were not yet harmonized. The problem with proportioning methods used for stabilizations is in many cases that the target values are not completely specified and that the requirements vary for different stabilization methods. The suitability of the laboratory test methods used in other Nordic countries for Finnish conditions was tested in experiments carried out in the framework of the project.

Based on the present state survey, the key issues in preparing laboratory samples with stabilization mixtures are sample compaction and aging. The principle where at first the theoretical maximum density of the mixture is explored and thereafter the actual comparison samples are compacted to only a certain share (95...98%) of this maximum density is becoming the compaction procedure for cold mixtures. The significance of density and compaction both in laboratory sample preparation and on-site stabilization work became evident from the results of the laboratory tests as well as the full-scale test. The gyratory compactor method was adopted for the selection of sample target density instead of the Proctor test. Empirically, it was also found that the optimum moisture of the mixture could be selected using gyratory compactor experiments instead of the Proctor test.

Another factor that has a significant effect on the properties of stabilizations is the moisture of the mixture at the time of compaction. The moisture content of the mixture is particularly significant on the site, as it has an effect on the density of the stabilized course. Moisture is important also in the preparation of the laboratory samples, but compaction of the samples to the selected target density reduces the significance of slight variation in mixture moisture content in the preparation of laboratory samples.

As for the research methods used in Finland and the other Nordic countries, perhaps the main difference is in the storage of the bitumen stabilization mixture before the testing of mechanical properties. In Norway and Sweden, seven days of storage in 40°C is used, whereas in Finland storage at room temperature has been selected. Tests carried out in the INFRA-STABIL project found that if necessary, it is possible to shorten the storage time between the preparation and testing of the bitumen stabilization samples with heat treatment, i.e. replacing the storage conditions of 28 days in 22°C with 7 days in 40°C.

3.3 Field measurement methods

A well-designed, implemented and instrumented test road can be used to explore the effect of construction technique, materials and conditions on the state variables measured from the surface. A well-implemented and documented test road provides important information for assessing the service life of the road and its structure courses. In assessing the service life, a test road is useful only if the monitoring period spans several years and, if possible, continues until the appearance of damages. One- or two-year visual monitoring does not serve this purpose. The Vöyri test structures were not instrumented due to costs. However, instrumentation of the test structures would offer service life data considerably more quickly and reliably than just surface measurements and visual observations.

3.4 Service life evaluation methods

The study proposes methods for assessing the service life of stabilization products, based on research results from project reference materials or possible laboratory tests carried out in connection with product approval surveys and test structures and application of the FINNRA specification programme.

No explicit tools yet exist for service life design in Finland. The beginning of damages can be assessed using the APAS 3 programme, and rutting can be evaluated using the deformation tool's draft version at the time of the study (Figure 5). Both tools can be developed further with regard to computation technique as well as material models and material data. At the time of the study, damage speed could only be assessed using statistical models.

Longitudinal unevenness, when it is due to the stabilized course, is mainly due to deviation caused by production engineering, and it was not explored in this research.

Proceeding to service life design requires documented data on the service life and structures, materials and action history of existing structures.

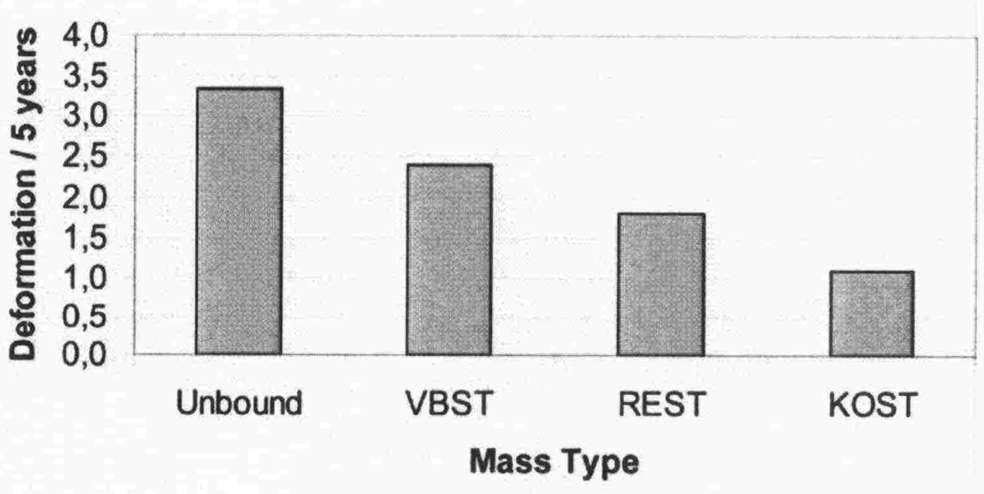

Figure 5. Rutting produced by the deformation tool when the material of the stabilized base course is VBST, REST or KOST. Traffic volume ADT = 1000 vehicles/day and 100 heavy vehicles/day.

3.5 Product approval methods

Studies producing reference data for stabilizations in accordance with FINNRA instructions were carried out within the framework of the study, with which a new stabilization product can be compared. The composition of branded product stabilization is secret and will not be marked in the product approval study report. The research organisation will carry out a product approval study on commission of the agent of the new product, exploring the durability properties of the new product.

The new product will be compared to the corresponding properties of the closest reference stabilization mixture. The reference stabilization types include VBST, KOST, MHST and SST stabilization conforming to the FINNRA stabilization specification, and for each branded product stabilization, the reference stabilization to be selected will be the one whose binder is the closest to the binder of the surveyed branded product.

So far, no agreement has been made on which party or authority will make the product approval decision for a new stabilization product.

4 RECOMMENDATIONS

New data on the properties of stabilizations, the variables influencing their quality and performance obtained from the study have been partially adopted in the revision of the Stabilization specification, which took place during the final stages of the research project. In future the requirements for base course stabilizations will be presented in the general construction quality requirements (InfraRYL) and in the Finnra's new Stabilization specification.

Based on results of the INFRA-STABIL project the following recommendations are made:

- Construction specifications should harmonize the current mixed practices in declaring the contents of mixture ingredients. All contents should be declared as percentage from the dry (water-free) stabilization mixture. This also means a change to the practices followed in this study.
- The stabilization sample preparation and testing instructions should be revised. It is recommended to use a method based on the gyratory compactor in the sample preparation of stabilization mixtures as the method for choosing the target density (especially bitumen-containing mixtures).
- The proportioning criteria for experimental proportioning methods and empirical selection method of additional bitumen content for REST mixtures should be revised in accordance with the results of the project.
- An anti-stripping agent should be used in foam bitumen stabilization mixture, unless it can be experimentally proven that no bonding agent is necessary. The bitumen content of the stabilization mixture has a considerable effect on properties, so it should be managed either by means of preliminary tests or site quality control.
- The foaming temperature of bitumen in foam bitumen stabilization should be significantly increased. The suitable desired value with regard to foam distribution is 170°C.
- The suitable starting point for proportioning in composite stabilization is cement addition approximately 1% and cement/bitumen ratio of approximately 0.33.
- Salt-frost and freeze-thaw attacks have a considerable decreasing effect on the stiffness and durability of stabilization samples. The stiffness modulus to be used in design should be selected, taking into account the actual weather conditions of the application site. When choosing the modulus, it is crucial whether the stabilization is allowed to freeze when wet and whether it is subject to frost-salt attacks.
- The stabilization design procedure should be described and specified (principle of design procedure, application method).
- It is important for the success of implementing the stabilization project that the contractor carrying out of the work is sufficiently familiar with the damage and action history, structure courses and materials to ensure the selection of the correct stabilization method and proportioning. It would be appropriate for the client to assume responsibility for having these surveys made or prepared in advance.

- The density monitoring methods should be standardised and specifications issued (more specific instructions for the use of quality assurance methods, e.g. Troxler direct measurements, are recommended instead of surface measurements),
- Instructions for the use of roller density monitoring equipment should be composed and made a part of site quality documentation,
- Instructions for work-time tests, explorations and sample preparations should be issued so that e.g. quality assurance sampling frequency and composition would be representative.

Follow-up of the Vöyri test road should be continued for several years after the completion of the project. It is possible to assess the ratio of deformation and after-compaction based on the state of structure displacement, and sampling can be used for producing data on the integrity of the bound course.

The test road should not be used for short-term comparisons of work techniques or material technology. The objective should be a long-term follow-up period based on a hypothesis, after which conclusions are made based on the work hypothesis and the results. The compilation and storage of material should also be planned and verified.

5 REFERENCES

Reports of Infra-Stabil project:

[1] Pienimäki, M., Laukkanen, K., Bitumia sisältävien kerrosstabilointien pohjoismaiset testausmenetelmät (Nordic test methods for bituminous base course stabilization. State of the art report). In Finnish, Helsinki 2007, Finnra report 43/2007.

[2] Laukkanen, K., Laaksonen, R., Bitumia sisältävien kerrosstabilointien kehittämistutkimus. (Bituminous base course stabilization development. Laboratory study). In Finnish, Helsinki 2007, Finnra report 44/2007.

[3] Laaksonen, R., Laukkanen, K., Kerrosstabilointien täysmittakaavakokeet. (Full Scale Trials with Stabilized Road Base Courses. In Finnish), Helsinki 2007). In Finnish, Finnra report 45/2007

[4] Laukkanen, K., Laaksonen, R., Stabilointien käyttöiän arvioinnin ja tuotehyväksynnän kehittäminen). In Finnish, Helsinki 2007, Finnra report 46/2007.

[5] Laukkanen, K., Laaksonen, R., Kerrosstabilointien kehittämistutkimus INFRA-STABIL. Projektin yhteenveto. (Base course stabilization development project INFRA-STABIL. Summary report). In Finnish, Helsinki 2007, Finnra report 47/2007.

[6] Laukkanen, K., Laaksonen, R., Base course stabilization development project INFRA-STABIL. Summary report. Helsinki 2007. Finnra Report 48/2007.

Reports [1-6] have been published on Finnra*s internet site:
www.tiehallinto.fi/julkaisut

ISSN 1459-1553
ISBN 978-951-803-969-6
TIEH 3201073E-v